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When looking at the constitutive elements of Jørn Utzon's designs, it is possible to discover and identify at least two original approaches to variation and repetition. The first relate to his awareness on the issues of construction. The repetition of a component becomes the expedient by which complex geometrical and constructional problems can be rationally solved, as in the case of the shells of the Sydney Opera House: the construction of their complex geometry was simplified and rationalized with a brilliant solution that allowed employing only a limited set of standard mass-produced ribs components. The prefabricated components are combined in such a way to achieve a unified form while incremental is at once flexible, economic and organic.

The second relate to his refusal of reductionist approaches: in his design the variation of a component allows to embrace the complexity and the multifarious. Therefore, a structural component can vary its shape and adapt to the states of stresses it is subjected to, as for example the concourse beams of the Sydney Opera House. Its folded plate roof is made of an array of identical beams whose corrugation varies along their span to sustain adequately the prestressing and to be structurally most effective. Among the possible ways to reconsider Utzon's legacy, one can look at those strategies for variation and repetition in the light of the recent development of parametric modeling, computational techniques, digital fabrication and their application in architectural design. Parametric software enable the possibility to explore almost effortlessly infinite geometric variations that can be coupled with performance simulations, optimization and iterative design processes, enriching and potentially infinitely expanding a design space whose roots can be found in much of Utzon's work. These approaches can be translated in a computational environment to Performance-Aided Design (PAD).

Performance-Aided Design (PAD)

PAD is a term that indicates the shift in the use of CAD tools from a mere translation in a digital environment of the operations once carried on on paper to an evolving paradigm where the increasing integration of parametric tools and performative analysis is changing the way we learn and design. PAD is coined in 2012 during the teaching experiences at the Master of Architecture and Design at Aalborg University.

The aim of PAD is the development of the tools and the understanding required to develop integrated design with respect to form, material, structure and fabrication. Parametric design environment supports the definition of advanced geometry, and the interaction between geometry and structural analysis. Finite Element Method is used as a design tool since the initial stages of design, in order to include structural considerations early in the architectural design process. PAD can be regarded as a new paradigm to, in a short time, achieve an intuitive understanding of the structural behavior of different solutions thanks to the provided tools that enable real-time feedback loops from geometric exploration of forms and performative analysis. The proposed methodology includes the extensive use of feedback loops from exploration of form and structural analysis, and it can be applied to include other performance criteria as acoustic and environmental analysis. The ultimate goal is to enable the possibility to create a synthesis of architectural, structural and acoustic requirement in complex buildings by using parametric design tools that support the definition and control of advanced geometry, digital fabrication and performance analysis.

Following the two above mentioned approaches, a proposal for the summer school theme is formulated. The aim of the summer school is to explore new approaches to design in the line of Utzon´s work, by extending his design principles with the use of computational techniques in a parametric design environment. The summer school should be a hands-on learning environment where theoretical knowledge is coupled with physical and practical assignments related to the design theme.

Construction of complex three dimensional structures can be greatly simplified with the use of elements that can easily be operated by few people without the use of mechanical lifts. Innovative researches in rationalization of construction use optimization strategies to employ short and standardized components for the fabrication of free-form geometries, as in the case of reciprocal structures, where short standardized components can be used to generate potentially infinite variety of complex three dimensional structures (Parigi & Kirkegaard, 2014). The combination of folded plates and reciprocal system is the point of departure to extend the line of Utzon's work with the introduction of computational techniques in a parametric design environment.

The Reciprocalizer: embedded tectonics

According to the original and approved theme of the summer school, the author developed another iteration of a tool, the "Reciprocalizer" that allows to deal with the complex geometry of reciprocal structures (Parigi & Kirkegaard, 2013).

Reciprocal structures are low-cost and relatively simple in fabrication. It is extremely easy to assemble a reciprocal structure by interlocking, for example, three simple sticks in a closed circuit of forces. However, despite the simplicity and naivety of the joint, the geometry of reciprocal structures is particularly complex to predict and control or, in other words, to design. It cannot be conveniently described neither with available CAD software nor by hierarchical, associative parametric modelers. This can be explained from the fact that, in a reciprocal network of elements, each element position, at the same time, determine and is determined by the position of all the elements in the assembly. Instead, the geometry of the network is a property emerging, bottom-up, from the complex and simultaneous interaction among all the elements in the network. This behaviour reflect the non-hierarchical nature of reciprocal assemblies both geometrical and structural.

The “Reciprocalizer” is a tool developed to deal with the complex geometry of reciprocal structures. It can be used, for example, to arrange and solve the geometry of a reciprocal network of elements on arbitrary free-form surfaces. The output is the geometric data on the basis of which the joints and the shape of the elements can be further detailed while maintaining the geometric compatibility of elements.

This tool embeds all the necessary data for further shaping the elements’ geometry and for detailing the joints and the constructional aspects, with real-time feedback loops. Therefore it enables to:

i) adjust all elements’ size, orientation, depth according to a goal performance criteria, for example structural, acoustic, or environmental;

ii) to develop designs that integrate consideration of the assembling and fabrication by embedding the tectonics of the construction in the design process.

Application and conclusions

Here, two examples are provided that show the potential of the tool and its neutrality with respect to the development of original designs.

In the first example, the structure is composed by planar elements whose height is adjusted with a feedback loop with the structural analysis tool in order to improve the overall efficiency and to minimize the use of material (Figure 1). The orientation of the elements can also be adjusted in order to fit to other performance criteria as environmental analysis. Figures 2, 3 and 4 show the same elements with different orientation to increase/decrease the opacity of the structure.

In the second example, the structure is composed with curved interwoven planar elements (Figure 5). Such a shape allows elements to interlock without the need of notches that would weaken the joints. In this solution, the material is efficiently used, and the structure can be assembled with minimum effort.

The “Reciprocalizer” was developed in an attempt to extend the line of Utzon’s work with the introduction of computational techniques in a parametric design environment. Inspired by Utzon´s approach to variation and repetition, the aim of the tool is to focus on, and ultimately enable, performative analysis and construction–aware design.

Parigi D, Kirkegaard PH, Design and fabrication of free-form reciprocal structures, in Nexus Network Journal, Vol.16, no.1, 2014.

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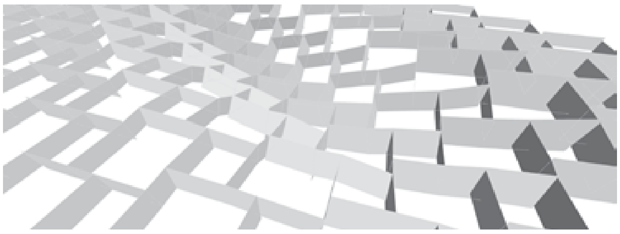
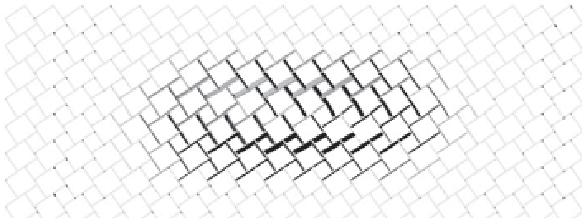


fig.1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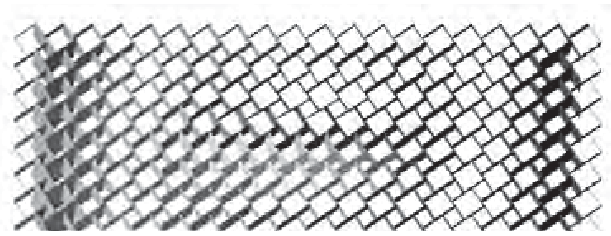
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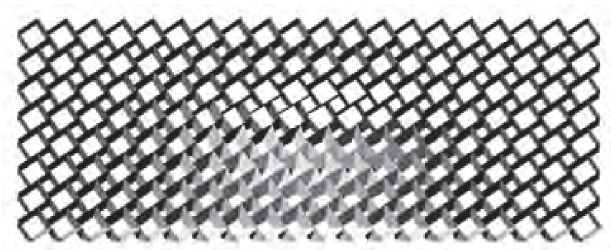
fig.4


fig.5